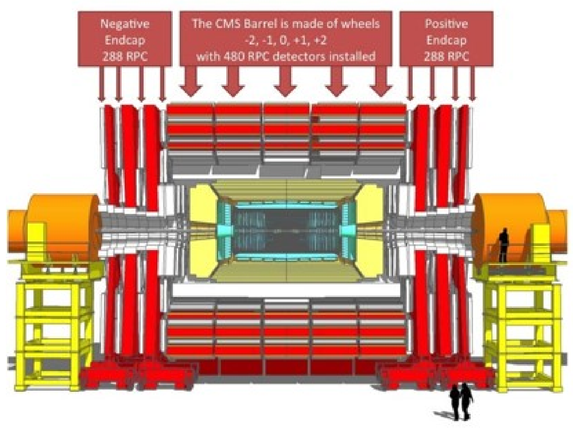
Long-Term Evolution of the CMS RPC Integrated Charge and Projections for the HL-LHC Era

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Automation

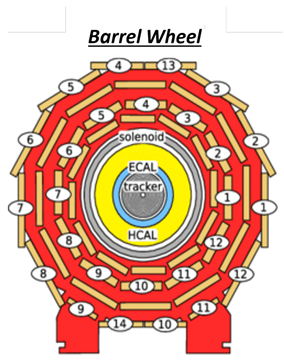
- **RPC Condition Data Automation** [1]
  - Automated processing of high-granularity RPC condition data from DCS logs and LHC operational cycles.
  - Synchronizes asynchronous, change-based raw data into query-optimized database tables ('RPCCURRENTS') using Oracle analytical functions.
  - Aggregates channel data into virtual detector objects (wheels, disks, sectors) for spatial and temporal analysis.
  - Enables systematic charge integration ($\int I\,dt$) at Luminosity Section (LS) resolution when the RPCs are at their working point (RPC ON : $V_{\text{eff}} \approx 9.55$ kV during collision and cosmic periods).



Schematic view of the CMS detector showing the layout of the barrel and endcap muon systems [2].

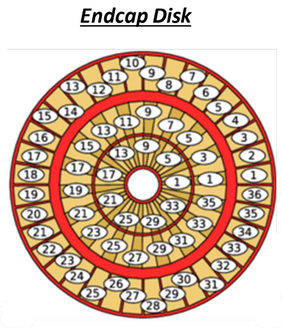
- This work extends the studies published in 2018, which covered only the 2009–2016 period [3].

- **RPC Barrel (RB) – 5 wheels:**



  - 480 RPC chambers arranged in 12 sectors and 4 stations (RB1 to RB4)
  - One HV channel per chamber.

- **RPC Endcap (RE) – 8 disks:**



  - 576 chambers distributed across 36 sectors and 2 rings.
  - 566 RPC chambers are grouped into 283 HV channels, with a 2:1 chamber-to-channel ratio.
  - 10 RPC chambers are connected one-to-one with 10 HV channels.

Total integrated charge density [$\mathrm{mC/cm^2}$]

$$\sigma = \frac{Q}{A_{\text{gap}}} = \frac{I\,\Delta t}{A_{\text{gap}}}, \tag{1}$$

- I is the average current read by DCS for each RPC HV channel in μA.
- Δt is the integration time.
- A_{gap} is the gap area in cm^2.
- Integration is performed only when the RPC is RPC ON (collision and cosmic periods).

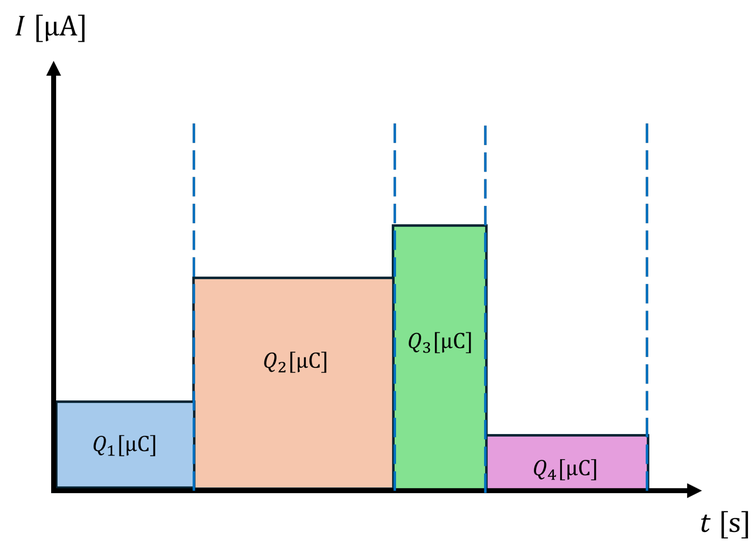
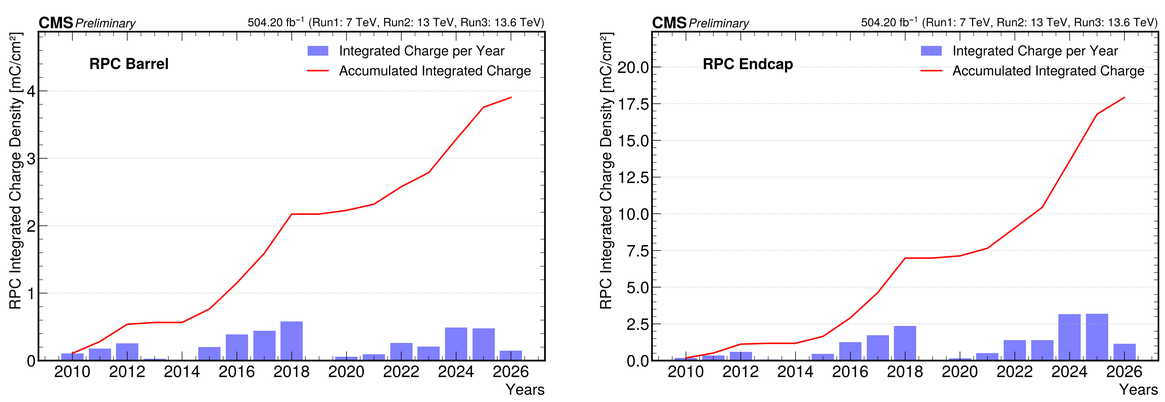


Figure 1. Schematic representation of the integrated charge calculation from RPC currents identified by the automation. The charge accumulated during each RPC ON period is obtained as $Q_j = I_j \Delta t_j$, and the total charge is $Q = \sum_j Q_j$. The corresponding charge density is $\sigma = Q/A_{\text{gap}}$.

Integrated charge Density (Run 1 - 3)

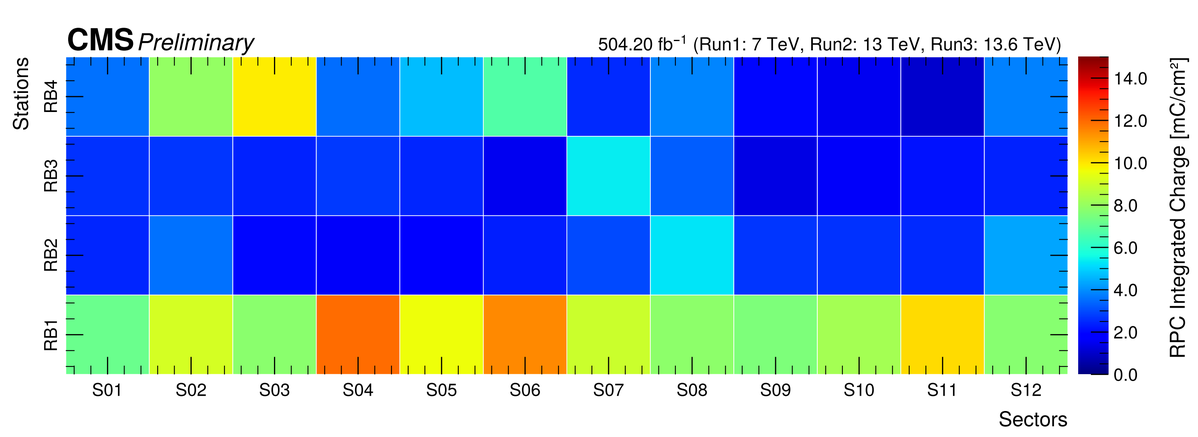


Historical evolution of the integrated charge density accumulated by RPC chambers during LHC Run 1–3. The left and right panels show the barrel and endcap regions, respectively. Blue bars indicate the yearly integrated charge, while the red curve shows the cumulative charge. Only periods with the RPCs operated at their working point (RPC ON) are considered.

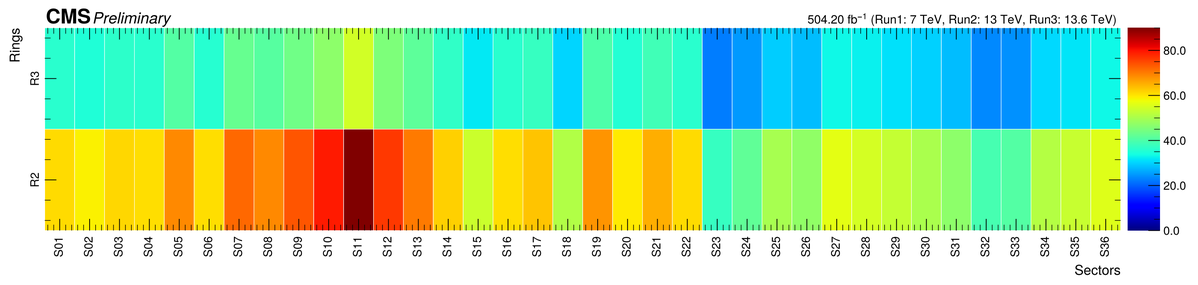
- **Longitudinal trend:** Steady cumulative growth matching LHC operational cycles; periods with no charge contribution correspond to scheduled technical stops and Long Shutdowns (LS).
- **Endcap vs. Barrel:** Endcaps accumulate $\sim 4.5\times$ higher charge (~ 18 mC/cm^2) than the Barrel (~ 4 mC/cm^2).

Integrated Charge Density (Barrel & Endcap)

- **Radial profile:** Highest charge density is concentrated in the regions closest to the interaction point and beam axis:
  - **Barrel (W-2):** Maximum values occur in station **RB1** (innermost radial layer).
  - **Endcap (RE+4):** Inner ring **R2** accumulates significantly more charge (up to ~ 90 mC/cm^2) than outer ring **R3**.
- **Sector variation (ϕ):** Charge accumulation varies across sectors in the same ring/station (e.g., sectors S07–S13 in RE+4/R2 exhibit the highest charge), due to background radiation patterns and shielding geometry.



R/ϕ distribution of historical charge density for barrel wheel W-2.



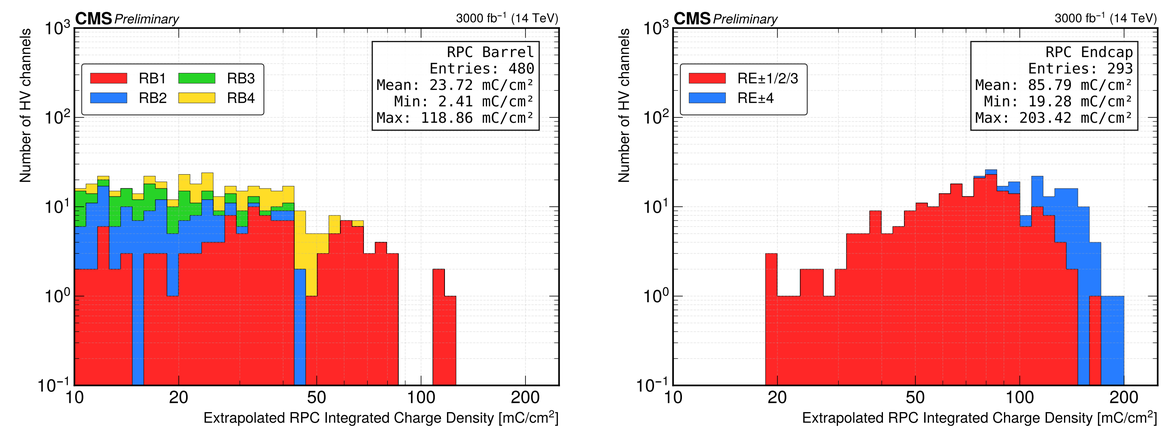
R/ϕ distribution of historical charge density for endcap disk RE+4.

- Complete R-ϕ distributions were generated for all barrel wheels (W-2 to W+2) and endcap disks (RE$\pm$1 to RE$\pm$4); selected representative examples (W-2 and RE+4) are shown.

Extrapolated Integrated Charge Density (HL-LHC)

$$\sigma_{3000} = \sigma_{\text{current}} \times \frac{3000\ \text{fb}^{-1}}{\mathcal{L}_{\text{current}}}, \tag{2}$$

$\mathcal{L}_{\text{current}} = 504.2\ \text{fb}^{-1}$ is the total current integrated luminosity recorded across Run 1–3 [4].



Extrapolated integrated charge density distributions for the RPC Barrel (RB) (left) and endcap (right) at 3000 fb^{-1}, scaled from the current 504.2 fb^{-1}. Barrel contributions are summed per RB station (RB1–RB4), while endcap contributions are grouped by HV channel. Maximum extrapolated values are ~ 119 mC/cm^2 for the barrel and ~ 203 mC/cm^2 for the endcap.

Summary

- **Data Automation:** Developed a robust database architecture (OMDS/Oracle) to aggregate asynchronous DCS data into synchronized time-series at Luminosity Section resolution during active *RPC ON* periods ($V_{\text{eff}} \approx 9.55$ kV).
- **Run 1–3 Charge Evolution:** Integrated charge density grew steadily up to an integrated luminosity of 504.20 fb^{-1}, reaching maximum historical values of ~ 15.03 mC/cm^2 in the barrel and ~ 91.96 mC/cm^2 in the endcap.
- **Spatial Distribution:** Maximum charge accumulation is strongly concentrated in regions closest to the interaction point and beam axis (innermost station **RB1** in the barrel and inner ring **R2** in the endcaps).
- **HL-LHC Projections:** Scaling to 3000 fb^{-1} predicts maximum integrated charge densities of ~ 119mC/cm^2 (RPC Barrel) and ~ 203 mC/cm^2 (RPC Endcap), providing essential input for detector longevity and aging assessment studies.

References

[1] A. Dimitrov et al., *CMS RPC Non-Physics Event Data Automation Ideology*, arXiv:2504.08991 [hep-ex] (2025).

[2] M. Abbrescia et al., *The CMS Resistive Plate Chamber system*, Nucl. Instrum. Meth. A **508** 137 (2003).

[3] A. Gelmi et al., *Study of the CMS RPC detector performance in high radiation background conditions*, PoS (EPS-HEP2017) 798 (2018).

[4] CMS Collaboration, *CMS Luminosity Public Results*, CERN-CMS-DP-2023-082 (2023).